DIRECT AIR TO GROUND COMMUNICATION

A Study Paper

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Mobile Technologies Division

Abstract

With the increasing demand for In Flight Connectivity, this study paper explores alternative means of providing the connectivity between the aircraft and the ground, called DA2GC, as compared to satellite backhaul. The study paper discusses the various methods through which DA2GC can be implemented based on Technical specifications of ETSI or ITU Recommendations and provides examples of global deployments and studies.

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Disclaimer: This study paper is intended purely for academic purpose and does not represent official view of TEC, DoT. The information present in the study paper is based on facts, which were current at the time of writing of the paper.

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1 Introduction

With the proliferation of mobile phones and internet, people expect to be always connected to the world, not just for the purpose of communications but also for business and entertainment. The availability of communication has percolated into each aspect of our life, be it home or office or travel. Particularly now, there is demand for availability of communication during air journeys which till recently were unconnected. Globally, some airlines have made available In-Flight entertainment where passengers through their devices access stored onboard content. However, these are not in real time and do not allow business/ personal communication/ entertainment in real time.

To provide a method to allow air passengers to communicate with the outside world in real time, the communication equipment on board the aircraft needs to be connected to the ground networks. A well-known method is to use satellite technology to connect the aircraft with the ground network. However, the drawback is that satellite adds latency, has restricted bandwidth and is expensive.

An alternative method is DA2GC or Direct Air to Ground Communication, wherein an onboard antenna picks up the signal from the nearest tower on the ground, and provides the connectivity. The DA2GC is akin to backhaul and within the aircraft, various technologies like WiFi, 3G/4G etc. can be utilized to connect to the customers. The DA2GC itself is enabled via variety of communication methods. The DA2GC system can support various types of telecommunication services, such as Internet access and mobile multimedia services, during flights. In addition, a DA2GC system could also support communication from aircraft to ground control called Airline Administrative Communications (AAC) services.

The following sections depict global deployments, system architecture, DA2GC technologies including frequency aspects, core network and conclusion.

2 Global Deployments

Global deployments including trials and Proof of Concepts carried out in the recent years are as below.

2.1 European Union

In EU, since 2018, European Aviation Network (EAN) consisting of Inmarsat, Deutsche Telekom and SkyFive (formerly Nokia) has deployed an air-to-ground system to provide connectivity to aircraft. EAN integrates Inmarsat's S-band satellite in the 2GHz MSS band with Deutsche Telekom's complementary LTE network (Band B65A Transmit 2170 MHz to 2200 MHz; Receive 1980 MHz to 2010 MHz) which has a spectrum allocation of 2×15 MHz and provides overall high-capacity coverage service in land area. EAN consists of 300 base stations with cell sizes of up to 150 km that are deployed all across Europe, typically at elevated locations. EAN services can be accessed on more than 150 routes across Europe. This LTE network has a modified physical layer to support the high speed. As per the information available, it provides:

- upto 100Mbps bandwidth to the aircraft in each of its A2G cells and lower latency as compared to satellite communication.
- The Installation time is of 9 hours only; aircraft spends 80% less time on ground than with competitive solutions.
- It is lightweight, with low drag equipment which means it has three times less fuel impact than any other system in the region.

2.2 China

In China 2012 onwards, DA2GC pilots based on SCDMA have been carried out. As of 2018, Civil Aviation Administration of China has organized an experimental verification project for the ATG-LTE technology in civil aviation applications with China Mobile and Air China. 52 ground base stations in the air traffic routes have been set up with more than 400 flight trails and a total bandwidth of 45-75 Mbps/ flight. Further, China Mobile has recently proposed a 5G Air-To-Ground network, using the 4.8-4.9 GHz spectrum.

SkyFive has recently announced a new strategic technology partnership with Airbus China Innovation Center to deliver a 5G air to ground connectivity solution for the Chinese market.

2.3 Japan

In Japan, Air-to-ground (ATG) communication system with aircraft, which achieves over 100 Mbit/s transmission speed, is being studied. In the system, the 40 GHz band facilitates broadband wireless communications on airplanes and on the ground. Airplanes fly over ground tracking antennas arranged at regular intervals. As the aircraft passes overhead, the antennas hand over service one after another to the aircraft. The 40 GHz band is not used heavily in commercial applications and is expected to facilitate the broadband communication system.

2.4 USA

In USA and Canada, Gogo, a in-flight internet provider, has been providing in flight connectivity since 2008 through more than 225 base stations. GoGo network operates at 850 MHz with 2 MHz bandwidth (BW) for uplink and 2 MHz BW for downlink by using 3G Code Division Multiple Access Evolution-Data Optimized (CDMA EvDO) standard. The network provides DA2GC capacities up to 10 Mb/s. As per news available in October 2019, GoGo has plans to setup a 5G aviation network by upgrading their system by combining advanced beamforming technology with a proprietary modem and unlicensed 2.4GHz spectrum, for which it is partnering with Cisco, Airspan Networks, and First RF Corp. Existing 225-tower infrastructure will be upgraded to support higher data speeds and latency; it will be capable of supporting additional spectrum types and bands in the future, and have the ability to fall back to 3G and 4G service as necessary.

3 DA2GC System Architecture

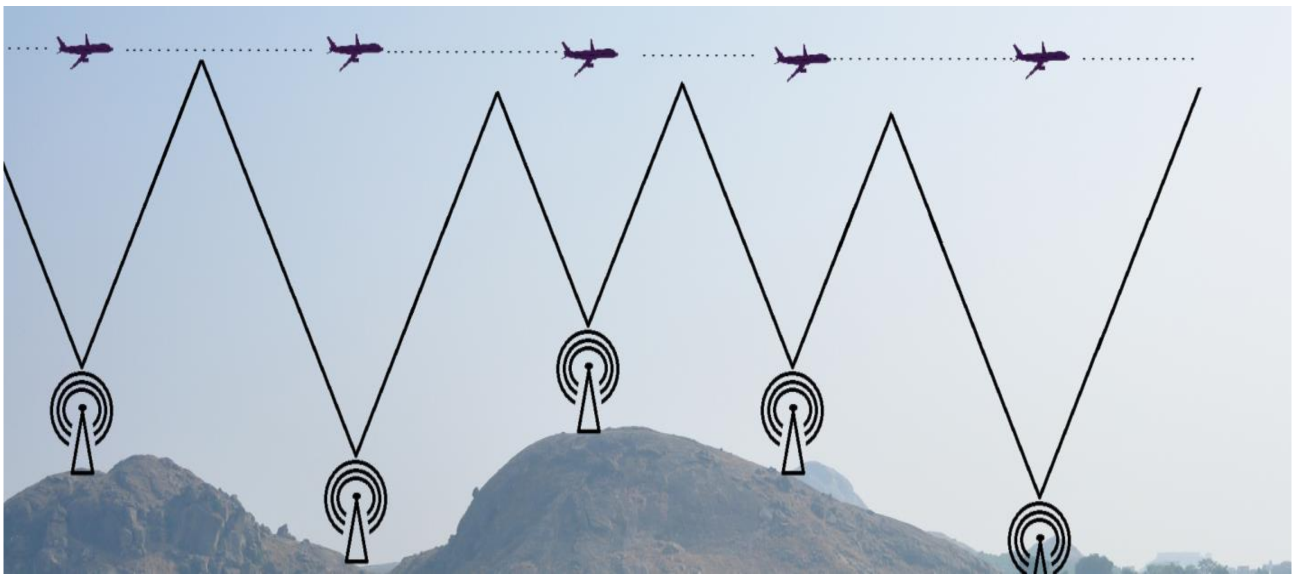

Figure 1 : DA2GC system representation

Direct Air to Ground Communication envisages a set of Base Stations suitably placed at the ground and directly communicating with airborne object, which may be an aircraft or any other aerial vehicle. These base stations transmit the radio waves to the airborne object that crosses the range of the base stations. While the airborne object moves, it connects to the base station within whose coverage range it is present and while moving connects subsequently to the different base stations in its path. The Figure 1 above shows an aircraft moving across the coverage area of different base stations while travelling towards its destination. When the aircraft is within the coverage area of a base station (say BS-1), it transmits and receives the signals from that base station (BS-1). When the aircraft crosses the coverage area of one base station (say BS-1) to another (say BS-2), it exchanges signal with that another base station (BS-2), and so on. In this way DA2GC system architecture works for the long flights.

Direct Air-To-Ground Communication (DA2GC) utilizes cellular technology to link the aircraft and the ground. These systems are implemented using three key infrastructure pieces: (i) Aircraft Station (AS), (ii) Ground Station (GS), and (iii) DA2GC Core Network. The aircraft station consists of the radio receiver and transmitter, as well as network appliances for handling in-flight entertainment systems which is available commonly on many aircrafts. Ground Stations are towers that communicate with aircrafts in its coverage area. These stations are similar to cellular towers, with the exception that their radio transmitters are directed upward, and that they are located at much greater distances ranging between 50 and 150 Km. DA2GC systems also operate their own core networks, analogous to modern cellular networks, which handle aircraft mobility and tower handoffs. Traffic from aircrafts is received by each GS, and tunneled through to the DA2GC's Core Network before egressing into the public network. The DA2GC System Architecture is depicted in Figure 2 below.

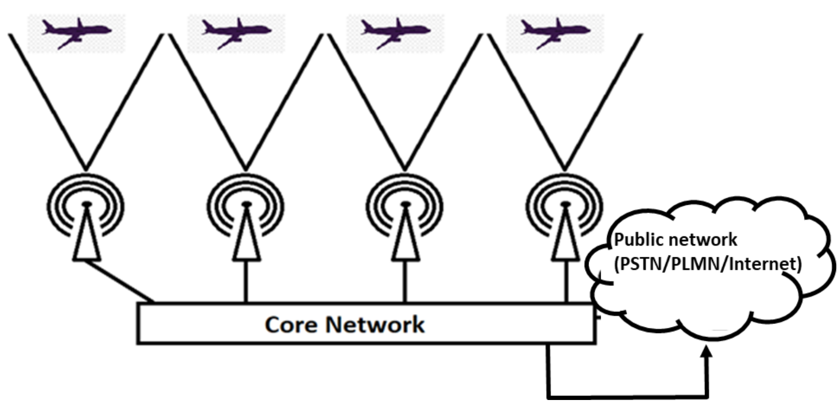

Figure 2 : DA2GC system architecture

4 DA2GC Technologies

The connectivity between the base stations on the ground and the receivers on the aircraft can be provided through multiple technologies. Several options like LTE (modified at the physical layer), UMTS, communication in unlicensed bands etc. have been used in trials and proof-of-concepts for provision of connectivity. Such technologies are described below.

4.1 DA2GC system based on LTE

The DA2GC system based on LTE technology, as per ETSI TR 103 054, later standardized as ETSI EN 302 574-1 V2.1.2 complies with 3GPP LTE Rel. 8+ specifications. However, synchronization algorithms as well as the maximum TX power of the On-board Unit (OBU) are to be modified compared to terrestrial mobile radio usage in order to cope up with the high Doppler frequency shift caused by aircraft speed and large cell sizes. In addition, the Ground Station (GS) antenna adjustment has to be matched to cover typical aircraft altitudes between 3 and 12 kilometers by adaptation of vertical diagrams including antenna up-tilt. When commercial, this solution will be able to provide in-flight mobile voice and broadband data communication services. The major building blocks of the DA2GC system based on LTE are: –

(a) Service access network infrastructure on-board the aircraft, e.g. Wi-Fi coverage, GSM, LTE etc. on-board aircraft (both already standardized and certified for on-board implementation).

(b) Broadband DA2GC network infrastructure on-board aircraft, e.g. modem (OBU), interface to on-board network(s), external antenna, cabling, etc.

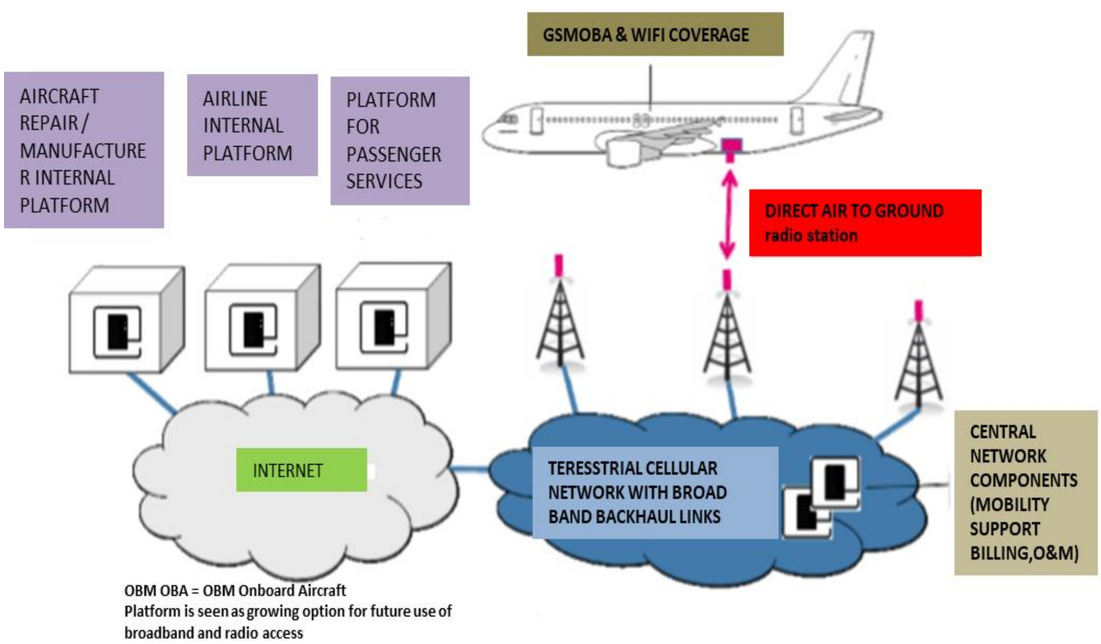

Figure 3 : DA2GC system based on LTE
(Source: ETSI TR 103 054)

Paired spectrum of 2 × 10 MHz for frequency division duplex (FDD) operation is considered necessary to cope up with short-to-medium-term demand. Unpaired spectrum of 20 MHz for time division duplex (TDD) operation is also an option, but system performance would slightly suffer due to guard time intervals required for large cell sizes. Further, due to wave propagation aspects (e.g. increased path loss, Doppler shift), spectrum above 6 GHz may not be suitable for such an application.

4.2 DA2GC system based on Beam Forming

The DA2GC system based on beam forming, as per ETSI TR 101 599, makes use of adaptive beamforming antennas in order to achieve the desired system performance whilst maintaining lower transmit power levels than would otherwise be necessary. This feature eases co-frequency sharing with other systems by minimizing interference into other services and, at the same time, reducing the impact of incoming interference on the achievable link performance.

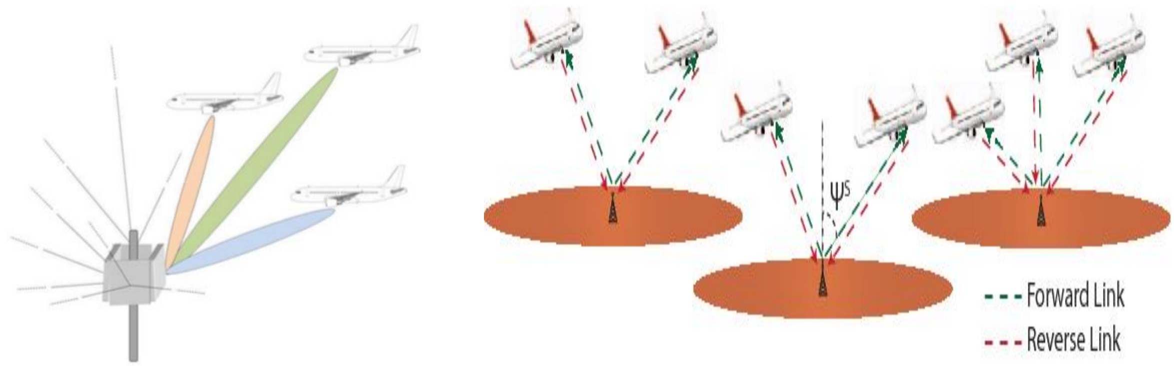

Figure 4A: Ground Station antenna showing three beams per quadrant

Figure 4B: Beam Formation for Forward & Reverse Link between flight and Base Station

Figure 4 : DA2GC system based on Beam Forming

(Source: ETSI TR 101 599)

The DA2GC system based on beam forming is currently optimized for use in the frequency bands around 2.4 GHz and 5.8 GHz. However, the technology is capable of operating in any frequency band within the range from 790 MHz to 6 GHz and the system can operate with variable bandwidths in any sub-band within the relevant frequency range.

4.3 DA2GC system based on UMTS TDD

The DA2GC system based on UMTS TDD, as per ETSI TR 103 108, makes use of commercial off the shelf equipment and complies with the 3GPP Release 7 standards. A separate frequency converter is used to support operation in the 5855-5875 MHz band. To support increased range, changes in the physical layer like Doppler shift compensation, extended timing advance have been specified. Any co-channel interference is minimized using ground station antenna control whereby sectors not required by aircraft at a given time are not illuminated (i.e., the transmitter is inhibited).

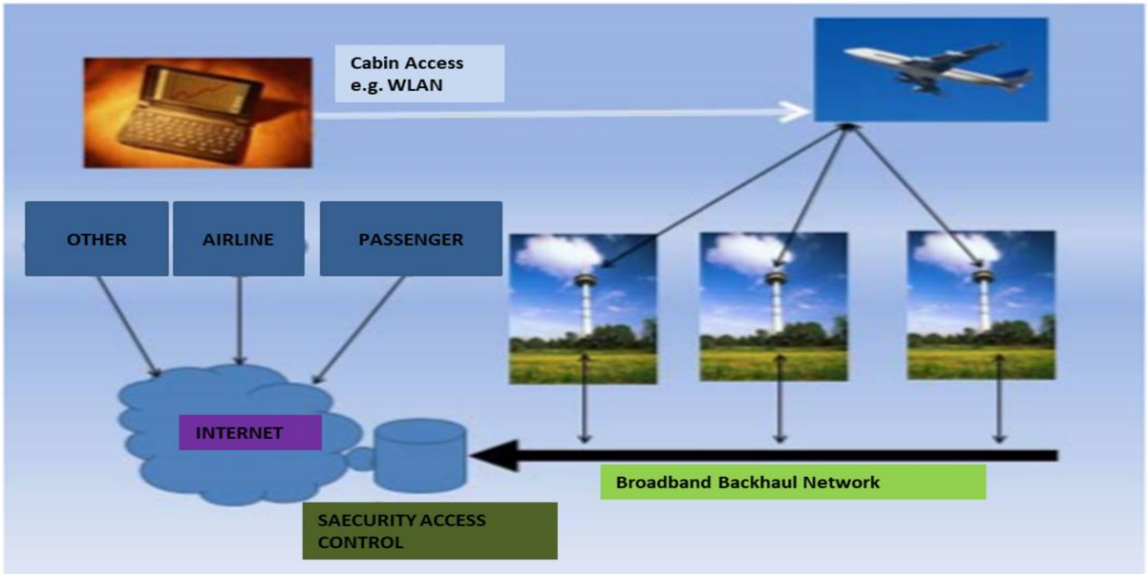

Figure 5 : DA2GC system based on UMTS TDD
(Source: ETSI TR 103 108)

The DA2GC system based on UMTS TDD can use switch-selectable bandwidths of 5 or 10 MHz although single channel operation is possible, the use of additional channels reduces potential inter-cell interference and also any interference to other systems. The required spectrum is 20 MHz thereby enabling 2 × 10 MHz or 4 × 5 MHz channels. The system does not require contiguous spectrum. ETSI TR 103 108 proposes that this system operates in the band 5855-5875 MHz. However, the system may operate within the extended band of 790 MHz to 6 GHz, e.g. in the bands 1900-1920 MHz and 2010 - 2025 MHz which were designated for terrestrial mobile systems based on UMTS-TDD technology.

4.4 DA2GC system based on CDMA Multi-Carrier Technology

The DA2GC system using CDMA Multi-Carrier technology is currently deployed and operational within United States. It uses a modified version of the IMT-2000 CDMA Multi-Carrier network to provide a high-speed connection directly from the aircraft to the ground. Each Radio Access Network (RAN) supports 1 carrier and 6 sectors. Each sector can generate about 2.2 Mbit/s peak throughputs. The end users inside the airplane are on a local 802.11 access network connected to an access point (AP). The AP is connected to a 1x EV-DO card, which is the access terminal (AT) for the 1xEV-DO network and a point-to-point protocol (PPP) session is set up between the AT and the Packet Data Serving Node (PDSN). In addition to data, VoIP can be supported as well. A cabin 2G/3G Pico cell can be deployed to allow passengers voice calls (incoming/outgoing) on their own personal cellular phones. The authentication, authorization and accounting (AAA) server, one or more RNCs, PDSN, media gateways (MGW), Soft switch which controls the MGWs, SIP Server/Registrar can all be co-located in one location.

Some of the characteristics features of this network are:

- Very large cell size (up to 400 km radius);
- modifications made to the IMT-2000 CDMA Multi-Carrier 1xEV-DO air interface to accommodate extended cell coverage and airplane speed; and
- deployment using off the shelf components such as Radio Access Networks (RANs) and Radio Network Controllers (RNCs).

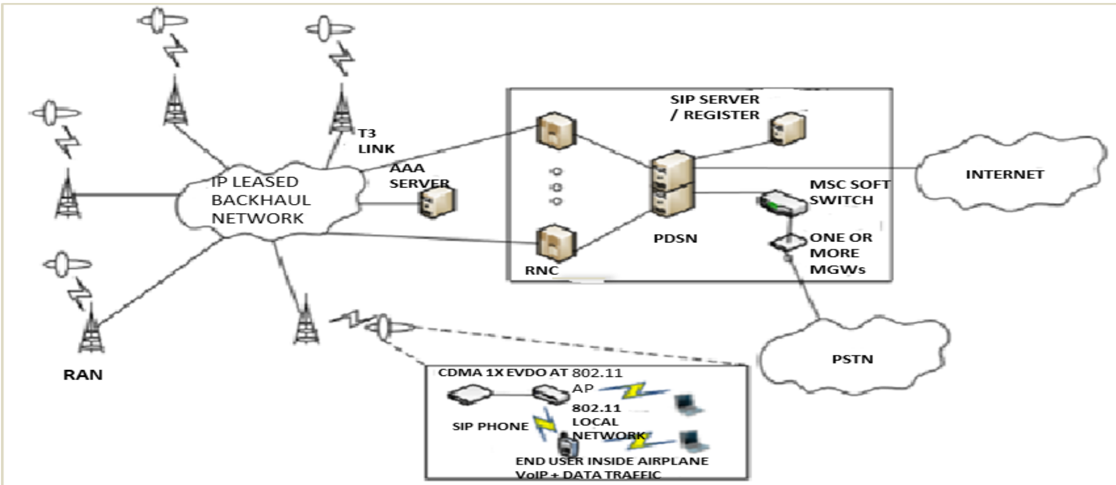

Figure 6 : DA2GC system based on CDMA Multi-Carrier Technology

(Source: ITU-R Report M.2282)

It operates in the 849-850.5 MHz and 894-895.5 MHz bands and enables in-flight broadband services to all Wi-Fi enabled laptops, notebooks and smartphones.

4.5 DA2GC system based on SCDMA

The DA2GC system based on the SCDMA complies with the broadband wireless access standard as in Recommendation ITU-R M.1801. The basic system architecture is shown in Fig. 7. The system includes base stations (BTS) on the ground connected to PSTN, Internet and airborne terminals with interfaces to other on-board devices such as wireline hubs, Wi-Fi routers, pico-cells, among others. The radio access layer provides the radio access functions between the BTS and airborne terminals. The radio access layer performs basic radio access functions such as random access, paging, voice communications, data communications and trunked voice functions. The core control layer provides the control functions, such as handoff, roaming, terminal and user authentication, voice call switching, and data routing. It is between the BTS and other core network equipment such as data switches and routers, soft switches, media gateways, AAA (Authentication, Authorization, and Accounting) servers, billing servers, and HLR (Home Location

Register). This entire communication network including all layers supports separation of different data flows and also provides adequate protection on the data.

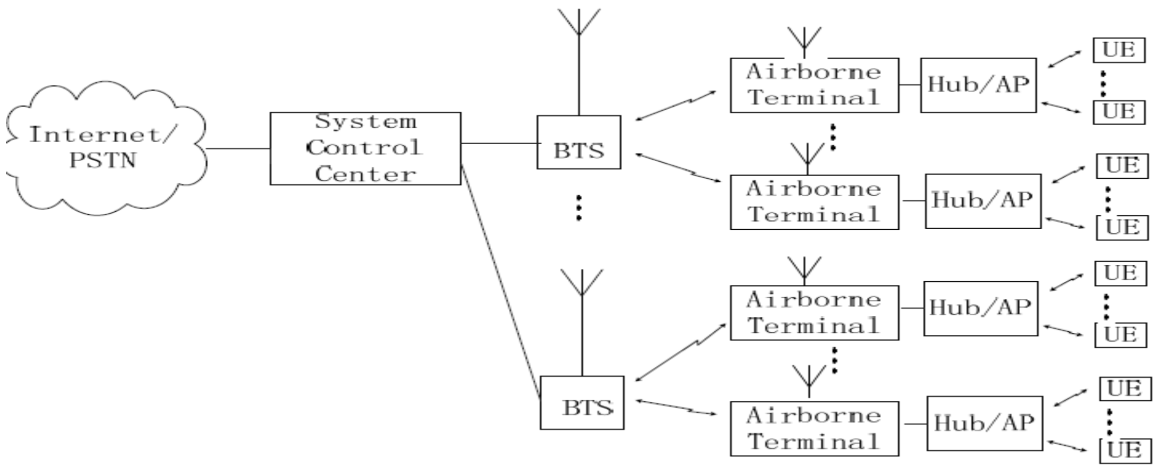

Figure 7 : DA2GC system based on SCDMA
(Source: ITU-R Report M.2282)

This system has been deployed by China. The SCDMA ATG wireless broadband access system contains base stations and terminals. The base stations are deployed to cover the entire flight course and communicate with the airborne terminals to achieve broadband communication between the ground and airplanes. The prototype systems have been successfully tested in trial flights at the frequency range of 1.785-1.805 GHz in China. The SCDMA radio interface supports a channel bandwidth of 1 MHz to 5 MHz in steps of 1 MHz. The system is based on TDD access scheme to separate the uplink and downlink.

4.6 Frequency Aspects

Proof of concepts and trials have been carried out in various frequency bands and technologies globally. However, deployments of DA2GC in Europe by the EAN (European Aviation Network) have been carried out in Band B65A (Transmit 2 170 MHz to 2 200 MHz; Receive 1 980 MHz to 2 010 MHz) using LTE technology as per the ETSI EN 302 574-1 V2.1.2 (2016-09). This technical specification includes the parameters like Receiver spurious emissions, Blocking characteristics etc. for the onboard terminal mounted on an aircraft (below the fuselage). The technical standards for other bands in which Proof of Concepts and trials have been carried out by China, Japan, USA and Canada are presently not available.

In the Indian scenario, on study of frequency allocation table and the corresponding notes in NFAP-2018 (National Frequency Allocation Plan-2018), it has been observed that currently there is no mention of any specific band for DA2GC in NFAP-2018. Accordingly, there is a need to clarify the frequency band for DA2GC type systems. Clarification on the frequency bands for DA2GC will help in development of standards for DA2GC, keeping in mind the Indian scenario.

If the frequency allocated for this service is the same as that currently in use for which standards are available and for which studies related to coexistence and interference have already been done, advantage of the developed ecosystem through use of such frequencies would be available.

However, if some other frequency band is allocated in India then the impact on existing network/frequencies allocated for different purposes and the coexistence and interference studies in the Indian scenario keeping the specific frequencies allocated will need to be carried out.

5 Core Network Aspects

Basically, from the perspective of the terrestrial core network, the DA2GC base stations are equivalent to the typical base station and through use of broadband backhaul network connect to the core network and hence to the external IP network.

From the viewpoint of implementation, there might be multiple DA2GC network operators (IFMC service providers) who will have their own core networks or there might be a single DA2GC network operator with own core network. The single DA2GC service provider might be a consortium of the different TSPs. Generally, since the DA2GC base stations have to be set up from scratch, a single DA2GC network may be set up. In the practical large scale implementation example available i.e. the European Aviation Network (EAN), a consortium runs the entire DA2GC network and uses the core network of the TSP which is a part of the consortium. Within the core network of the TSP, a separate part earmarked deals exclusively with the DA2GC traffic. This separation ensures that the multiple up-gradations added to the core network, which are generally not required by the DA2GC part, do not affect the DA2GC core network. Generally, civil aviation guidelines require that if any change is made to the network end to end certification needs to be done and having a separate DA2GC core network (even virtually) avoids this need for retesting.

Moving onto the network within the aircraft, where connectivity is being provided by either WiFi AP or an On Board BTS (OBTS), the user data generated by customers of different TSPs will be routed through the IFMC network provider core network and then the voice/data will be processed as in roaming. or to the respective TSPs core network. A gateway is there which aggregates the data from the multiple DA2GC base stations and routes them to the appropriate core network.

From the above points, it is clear that decision to have single/multiple DA2GC operator as IFMC service provider(s) will depend on the commercial basis and from the technical side, existing procedures for roaming can be used.

6 DA2GC versus Satellite Connectivity

Satellite has been used to provide connectivity between the aircraft and the ground network through which on board users can access the internet. Such satellite based connectivity solutions have been available for some time; however, the drawback is that since the satellite has a large footprint, the bandwidth provided by the satellite gets divided between multiple users that are within its coverage zone leading to a few Mbps per aircraft only. Further, since installation and commissioning of a satellite is expensive, the cost/Mbps is also high. Also, due to the large distances the signal has to travel, from aircraft to satellite to ground station, the latency is also high and is in the range of milli-seconds. However, satellite technology has been around for a long time and it is reliable with a well-developed ecosystem. A comparison of the connectivity options between aircraft and ground network in terms of DA2GC and Satellite is summarized in Table I.

Table I Comparison between DA2GC and Satellite based connectivity

	DA2GC	Satellite (L, Ku, Ka Band)
Throughput per aircraft	Up to 100 Mbps per aircraft	1-5 Mbps per aircraft
Area within which the bandwidth is shared among all aircraft	One A2G base station sector, which covers between 3.000 and 6.000km^2 of airspace	One satellite beam, which covers between 100.000 and 2 million km^2 of airspace
Scalability	Additional A2G base station sectors can be deployed for densification, e.g. near airports	Limited scalability, 1 or 2 spot beams can be added per geography (e.g. a continent)
Dedicated to aviation	Yes	No, bandwidth is shared among all users within the satellite beam
Ground connectivity at airports	Yes	No, due to too many aircraft concentrated in a very small area and aircraft satellite antennas overheating
End-to-end latency	< 50 ms	> 1000 ms
Data traffic kept in country	Yes	Depending on location of satellite ground station
Time to retrofit aircraft	8 hours, 3 engineers	5-15 days, 30 engineers
Structural aircraft changes	No	Yes
Additional weight on aircraft	10-15kg	200-300 kg
Cost of additional fuel consumption of aircraft	Negligible	50.000€ - 100.000€ per year

(Source: SkyFive Whitepaper "Spectrum considerations for Air-to-Ground communications")

7 Conclusion

The study paper discusses the concepts of DA2GC systems and also the various technologies through which DA2GC can be provided. Some of the advantages of this system are that it would enable flyers to avail data and voice services in a cost effective manner and also will help in transmission of the large amounts of data generated by the aircraft to the ground system for further processing, checking etc., which will in turn save cost on the satellite bandwidth currently needed. However, a major drawback is that this method will work only when the aircraft flies over land and not over water bodies.

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